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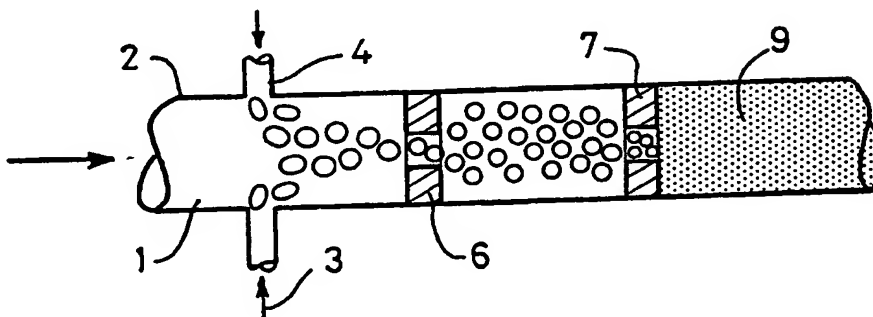
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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification <sup>5</sup> :  B01F 5/04</p>	<p>A1</p>	<p>(11) International Publication Number: WO 90/05583  (43) International Publication Date: 31 May 1990 (31.05.90)</p>															
<p>(21) International Application Number: PCT/GB89/01395 (22) International Filing Date: 22 November 1989 (22.11.89)  (30) Priority data:  <table border="0"> <tr> <td>8827197.8</td> <td>22 November 1988 (22.11.88)</td> <td>GB</td> </tr> <tr> <td>8828750.3</td> <td>8 December 1988 (08.12.88)</td> <td>GB</td> </tr> <tr> <td>8901648.9</td> <td>26 January 1989 (26.01.89)</td> <td>GB</td> </tr> <tr> <td>8906512.2</td> <td>21 March 1989 (21.03.89)</td> <td>GB</td> </tr> <tr> <td>8909312.4</td> <td>24 April 1989 (24.04.89)</td> <td>GB</td> </tr> </table> <p>(71)(72) Applicants and Inventors: DUNNE, Stephen, Terence [GB/GB]; 13 Sawyers, Elmsett, Ipswich, Suffolk IP7 6QH (GB). WESTON, Terence, Edward [GB/GB]; Willow Barn, Laxfield, Woodbridge IP13 8EH (GB).  (74) Agents: NASH, Keith, Wilfrid et al.; Keith W. Nash &amp; Co., Pearl Assurance House, 90-92 Regent Street, Cambridge CB2 1DP (GB).</p> </p>		8827197.8	22 November 1988 (22.11.88)	GB	8828750.3	8 December 1988 (08.12.88)	GB	8901648.9	26 January 1989 (26.01.89)	GB	8906512.2	21 March 1989 (21.03.89)	GB	8909312.4	24 April 1989 (24.04.89)	GB	<p>(81) Designated States: AT, AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CF (OAPI patent), CG (OAPI patent), CH, CM (OAPI patent), DE, DE (Utility model), DE (European patent), DK, ES, FI, FR (European patent), GA (OAPI patent), GB, HU, IT (European patent), JP, KP, KR, LK, LU, MC, MG, ML (OAPI patent), MR (OAPI patent), MW, NL, NO, RO, SD, SE, SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent), US.</p> <p>Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</p>
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(54) Title: LIQUID-GAS MIXING DEVICE



(57) Abstract

A device for mixing liquids and gases to produce a fine foam, for example for aeration or gas scrubbing applications, comprises a tubular passage (2) along which a liquid is fed under pressure and in which there are formed openings (4) to which gas is emitted. The resulting mixture is forced through a pre-mixing orifice (6), and through a sized restrictor (7) in which the mixture reaches supersonic velocity, subsequent shock waves producing a fine foam. The gas may be emitted through a Venturi (11), and the restrictor may be a de-Laval convergent-divergent nozzle (12).

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- 1 -

Title: Liquid - Gas Mixing Device

Field of the invention

This invention relates to a device for mixing a liquid with a gas to produce a fine foam.

Background to the invention

A need exists for the thorough mixing of liquids and gases, for example for foam formation, aeration, oxygenation or gas scrubbing. A usual requirement is for the liquid to present the largest surface area possible to the gas.

In recent years the demand for some of this equipment has been increasing because of the increased pressures on industry to minimise pollution. Examples are scrubbing noxious gases and oxygenating polluted rivers and lakes.

A need also exists for the thorough mixing of two or more liquids in for example the processing industries.

A number of devices have been used for this purpose, including Venturi tubes where for instance air is sucked into a pipe in the form of bubbles containing liquid, or liquid is sprayed into a Venturi-shaped tube containing gas. Velocities are kept above laminar flow levels to ensure turbulent flow and hence good mixing. Other mixing devices use blades and other mechanical devices with

- 2 -

moving parts to mix the two phases.

One example of such a device is an aerator used to aerate slurry on farms to accelerate the digestion of noxious bacteria and reduce the smell. The liquid to be aerated is pumped through a nozzle to increase its velocity and hence lower its pressure. After passing through the nozzle it enters a 'T' piece with a connection to an air supply at right angles to the flow of liquid. Air is dragged into the liquid flow in the manner of an ejector. The mixed flow is then passed through a long barrel the size of which ensures that the flow is turbulent, and hence rigorous mixing takes place.

Another example of such a device is an oxygenator used to oxygenate polluted rivers and lakes. A Venturi tube is used to drag oxygen into a flow of water. When this mixture expands in the expansion section of the Venturi tube vigorous mixing takes place because of the positive pressure gradient.

Yet another aerating device works by pumping liquid to a mixing head which contains a large number of stainless steel pins on both a stator and rotor. The rotor mixes the ingredients, and at the same time compressed air is introduced into the head to aerate the mix to a foam. In this device mixing is achieved by mechanical means.

It is an object of the present invention to provide a simple device having no moving parts and which is capable of producing fine foams.

- 3 -

Summary of the invention

According to the present invention there is provided a device for mixing a liquid with a gas to produce a fine foam, comprising: means for feeding a liquid under pressure along a passage, gas inlet means for admitting gas into the passage to mix with the liquid, and a sized restrictor through which the mixture is forced to pass, causing the mixture to reach substantially a supersonic velocity downstream of the restrictor, whereby the shock waves resulting from the subsequent deceleration of the mixture cause the mixture to be further broken up to produce a fine foam.

The passage may be a tube containing the liquid with one or more openings in which gas is allowed to pass and mix with the liquid to form bubbles. The resultant mixture is then passed through a carefully sized convergent-divergent nozzle which ensures that the mixed flow is first forced to go supersonic and then forced to pass through shock waves as it decelerates back to subsonic. Premixing of the liquid gas mixture can be enhanced by passing the mixture through an orifice or other mixing device upstream of the supersonic nozzle.

In one embodiment only one orifice is used. At the entrance to the orifice vigorous mixing ensures that a relatively fine mix is exhausted at the orifice exit. Choking of the mixture takes place at the exit (sonic velocity) and as the mixture expands downstream of the exit it goes supersonic for a short distance and finally passes through shock waves as it decelerates to a subsonic

- 4 -

condition.

In another embodiment a Venturi tube is used to suck gas into the liquid stream. This mixture is then passed through a supersonic nozzle.

In yet another embodiment the supersonic nozzle is a convergent-divergent or de-Laval nozzle. In this case large Mach numbers (ratio of velocity to sonic velocity) can be attained with associated strong shock waves and enhanced mixing.

In the case of mixing two or more liquids using said device, the gas will have to be separated from the liquid mixture at a later stage.

The device in accordance with the invention uses the little known phenomena of choking in gas-liquid mixtures. This phenomena is described below.

The phenomena of compressible flow in gas-liquid mixtures is described in detail in two papers: "Compressible Flow of an Air-Water Mixture through a Vertical, Two Dimensional, Converging-Diverging Nozzle" by J.F. Muir and R. Eichorn (1), and "One Dimensional Flow of Liquids Containing Small Gas Bubbles" by L.van Wijngaarden (2).

Mixtures of gas and liquids behave as if they are compressible, with the not very well known property of having a sonic velocity well below those of either of its constituents. The lowest speed of sound is reached at mixtures of 50% gas and 50% liquid by volume. For example in water/air mixtures at a pressure of 1 bar the velocity is approximately 20m/s, still well below the speed of

- 5 -

sound in air which is over 300m/s at 1 bar. These figures are taken from paper (2) above.

The result of this is that supersonic velocities can be achieved at relatively low velocities, with corresponding shock waves when the mixture is decelerated to subsonic speeds from supersonic conditions. Shock waves are characterised by very large pressure increases over short distances and hence very large shear forces, which break up the gas bubbles into smaller ones very efficiently. This phenomena is mentioned in paper (2) above.

This phenomena of supersonic flow and its associated shock waves is used in the present invention to break gas-liquid mixtures into fine foams.

Other features of the invention are defined in the appended claims.

#### Brief description of the drawings

The invention will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a sectional view of a device in accordance with one embodiment of the invention;

Figure 2 is a device similar to Figure 1 but incorporating a Venturi gas inlet; and

Figure 3 is a further device but incorporating a de-Laval nozzle.

- 6 -

Detailed description

Referring first to Figure 1, liquid 1 is forced along a tube 2 in which openings 4 are located from which gas 3 is injected into the liquid stream. The resultant bubbly mixture is passed through a pre-mixing orifice 6, which breaks up the bubbles and mixes the two constituents further and increases the volumetric ratio of gas to liquid because of the associated pressure reduction and expansion of the gas. The resultant mixture, which should preferably be near to 50% gas in volumetric terms, is then passed through a sized restrictor in the form of a second orifice 7 where the mixture reaches sonic conditions. As the mixture leaves orifice 7 and expands into the increased space, it goes supersonic and then decelerates to subsonic through shock waves, resulting in a foamy mixture 9.

The number of orifices used can vary depending on factors such as the gas to liquid ratios, the type of gas and liquid, and the flow rates.

Referring to Figure 2, liquid 1 is forced along a tube 2 and into a Venturi 11 in which openings 4 are located from which gas 3 is injected into the liquid stream. The resultant bubbly mixture is further broken up in the expansion section of the Venturi, resulting in an even finer mixture which should preferably be near to 50% gas in volumetric terms. This is then passed through an orifice 7 where the mixture reaches sonic conditions. As the mixture leaves orifice 7 and expands into the increased space it again decelerates and passes through shock waves, resulting in a foamy mixture 9.

- 7 -

Referring to Figure 3, liquid 1 is forced along a tube 2 to which openings 4 are located from which gas 3 is injected into the liquid stream. The resultant bubbly mixture is passed through a pre-mixing orifice 6 which again breaks up the bubbles, and mixes the two constituents further, and increases the volumetric ratio of gas to liquid. The resultant mixture, again near to 50% gas in volumetric terms, is then passed through a de Laval convergent divergent nozzle 12 where the mixture reaches sonic conditions at the throat. As the mixture leaves nozzle 12 and expands into the increased space it again goes supersonic and then decelerates to subsonic through shock waves, resulting in a foamy mixture 9.

Combinations of the three examples shown are also possible.

- 8 -

Claims

1. A device for mixing a liquid with a gas to produce a fine foam, comprising means for feeding a liquid under pressure along a passage, gas inlet means for admitting gas into the passage to mix with the liquid, and a sized restrictor through which the mixture is forced to pass causing the mixture to reach substantially a supersonic velocity downstream of the restrictor, whereby the shock waves resulting from the subsequent deceleration of the mixture causes the mixture to be further broken up to produce a fine foam.
2. A device according to claim 1 further comprising a pre-mixing orifice disposed between the nozzle and the gas inlet means.
3. A device according to claim 1 or claim 2 in which the gas inlet means comprises a Venturi tube forming part of said passage and having at least one gas opening at its throat through which gas is sucked into the flow of liquid.
4. A device according to any one of claims 1 to 3 in which the restrictor is a convergent-divergent nozzle, enabling high supersonic velocities to be achieved.
5. A device according to claim 4 in which the convergent-divergent nozzle is a de-Laval nozzle.
6. A device according to any one of claims 1 to 5 which is particularly adapted for use in the aeration of a slurry, or the oxygnation of a liquid, or for gas

- 9 -

scrubbing.

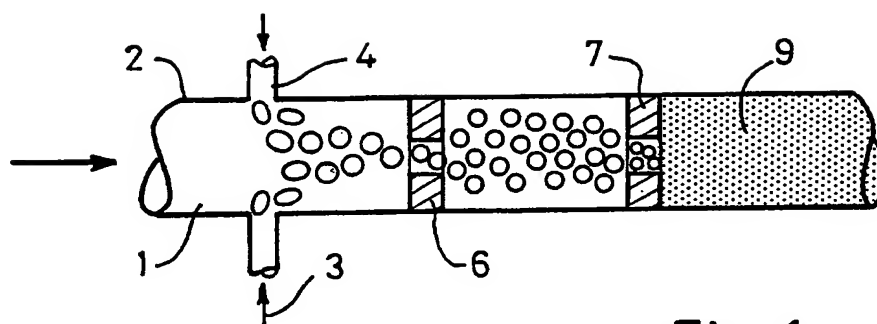
7. A device according to any one of claims 1 to 6 in which more than one liquid is mixed with the gas.

8. A method of mixing a liquid with a gas to produce a fine foam, comprising the steps of feeding a liquid under pressure along a passage, admitting gas into the passage to mix with the liquid, and forcing the mixture to pass through a sized restrictor to cause the mixture to reach a substantially supersonic velocity downstream of the restrictor, whereby the shock waves resulting from the subsequent deceleration causes the mixture to be further broken up to produce a fine foam.

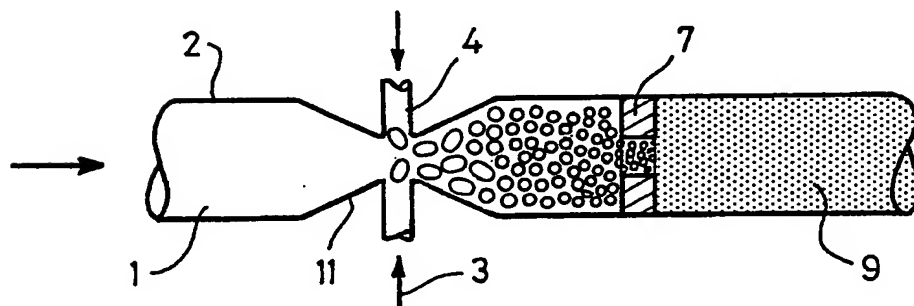
9. A method according to claim 8 and further comprising the step of passing the mixture through a pre-mixing orifice upstream of the restrictor.

10. A method according to claim 8 or claim 9 in which the liquid is a slurry to be aerated, or water to be oxygenated, or in which the gas is a noxious gas to be scrubbed.

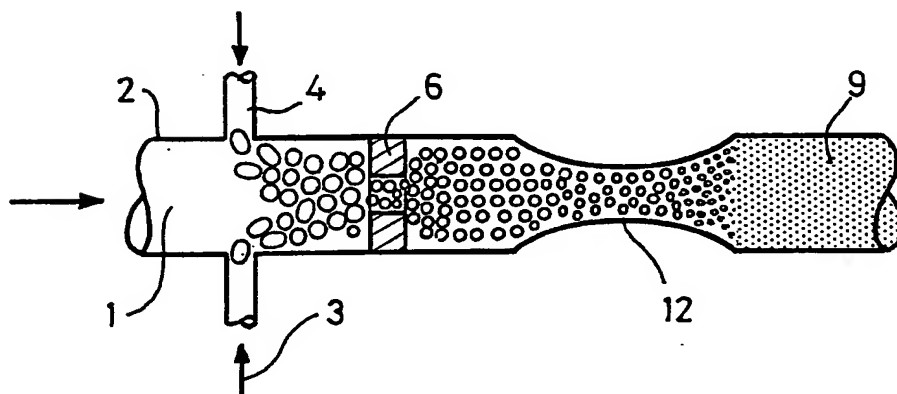
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*Fig. 1*



*Fig. 2*



*Fig. 3*

# INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 89/01395

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) *		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC <sup>5</sup> : B 01 F 5/04		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched ?		
Classification System	Classification Symbols	
IPC <sup>5</sup>	B 01 F 5/00	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched *		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> *		
Category *	Citation of Document, " with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
X	EP, A, 0157691 (COMPAGNIE FRANCAISE DE RAFFINAGE) 9 October 1985 see page 5, line 17 - page 6, line 4; figures 1,4  --	1,3,4,5,8
X	GB, A, 2096911 (D.R.P. SIMPKINS) 27 October 1982 see abstract; figure 1  --	1,2,8,9
A	GB, A, 2076672 (UNILEVER LTD) 9 December 1981 see abstract; figure 1  --	1,3,8
A	FR, A, 2484862 (INSTITUT NATIONAL DE RECHERCHE CHIMIQUE APPLIQUEE) 24 December 1981  -/.	1,3,6,8,10
<p>* Special categories of cited documents: <sup>10</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&amp;" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
26th February 1990	28.03.90	
International Searching Authority	Signature of Authorized Officer	
EUROPEAN PATENT OFFICE	T.K. WILLIS	

## III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
	see claims 1-6; figures 1,3 --	
A	FR, A, 881947 (DEUTSCHE SOLVAY-WERKE ACTIEN-GESELLSCHAFT) 12 May 1943 -----	

**ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO.**

GB 8901395  
SA 32463

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 19/03/90. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A- 0157691	09-10-85	FR-A, B 2561539	27-09-85
GB-A- 2096911	27-10-82	CA-A- 1180734	08-01-85
GB-A- 2076672	09-12-81	None	
FR-A- 2484862	24-12-81	None	
FR-A- 881947		BE-A- 445683 DE-C- 924749	

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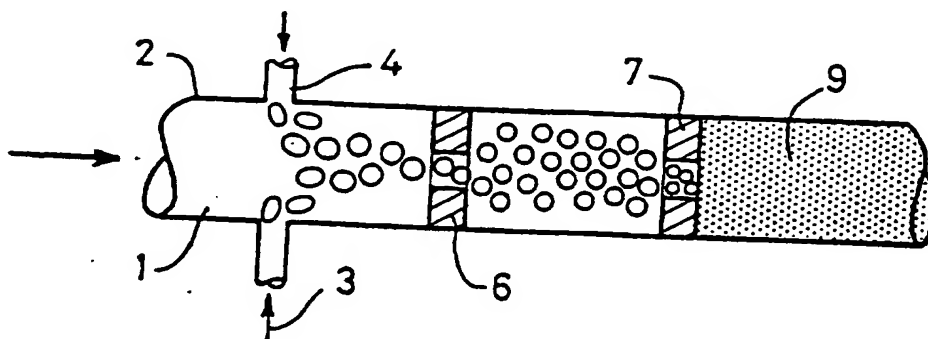
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